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(54) Abstract Title

Optical regenerating wavelength dependant routing interface

(57) The invention provides a regenerative interface (70, 80, 90, 100, 110, 120, 1500) for an optical communication system (10), the system (10) comprising a plurality of mutually interconnected bi-directional optical waveguide rings (20, 30, 40, 50, 60) in which radiation modulated with communication traffic propagates. The radiation is partitioned into 32 distinct wavebands. The interfaces (70, 1500) are included in the system (10) where communication traffic propagating in the rings (20, 30, 40, 50, 60) transfers from one ring to another. Each interface (70) is capable of providing an all-optical waveband reconfigurable communication link between the rings (20, 30, 40, 50, 60). At each interface (70), conversion of optical radiation to corresponding electrical signals only is performed for regeneration when transferring communication traffic from one ring to another, otherwise the system (10) handles the communication traffic in the optical domain thereby providing a potentially larger communication bandwidth compared to conventional optical communication systems. Radiation diverted between rings may be regenerated.

Fig.4.

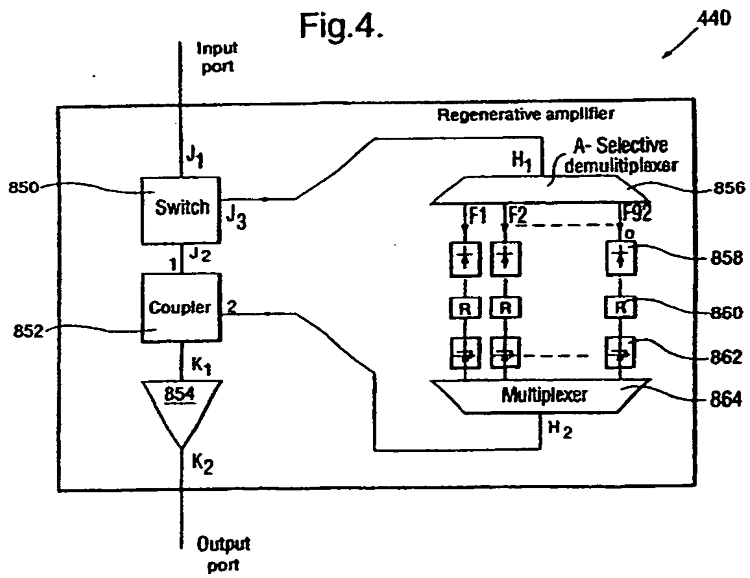

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Fig.1.

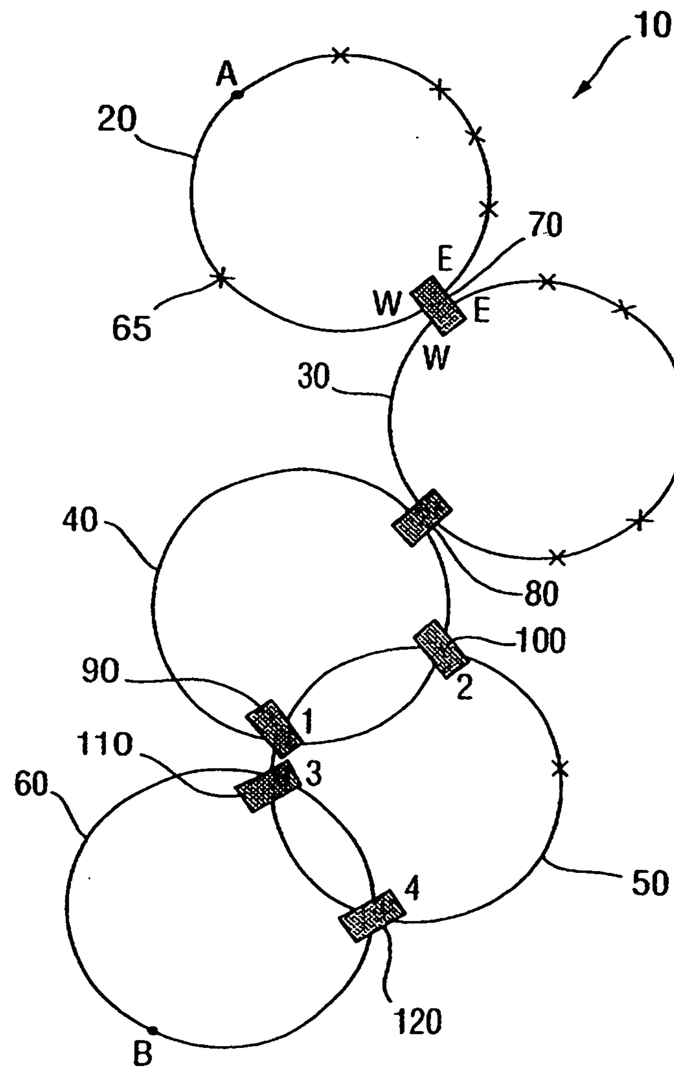
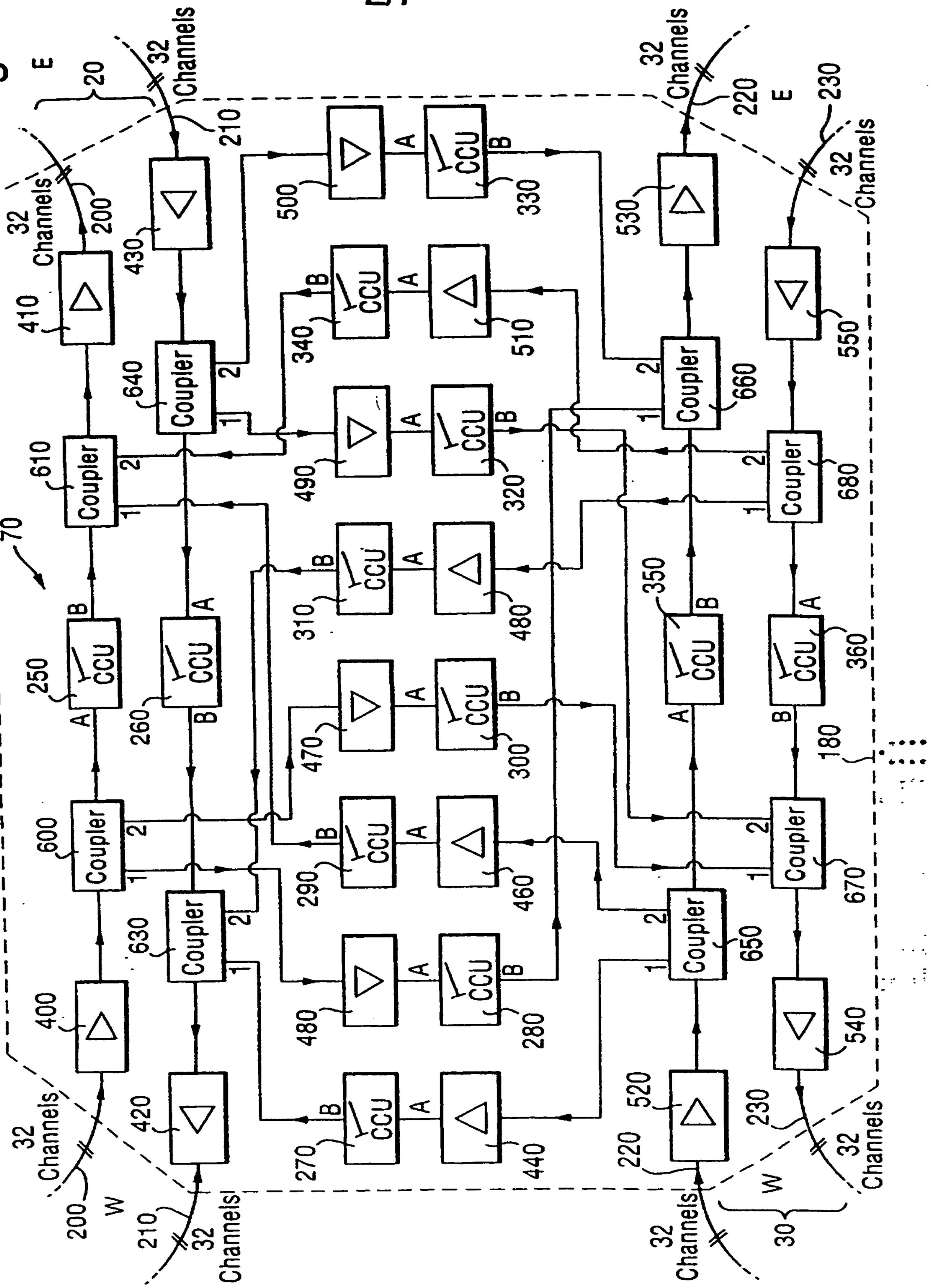
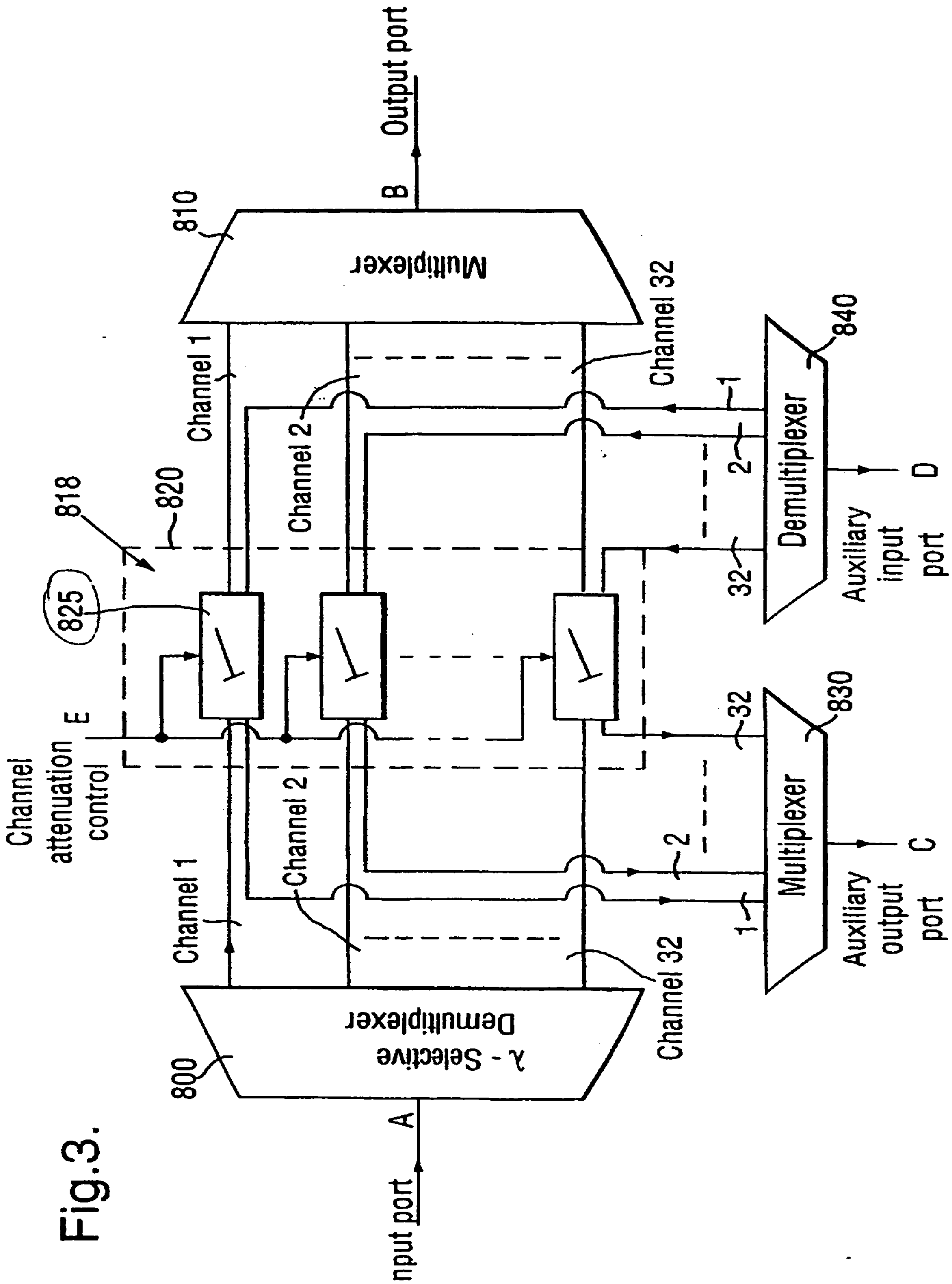


Fig.2.



70
20
30
E
W
32 Channels
200
210
220
230
180
Coupler
CCU
A
B
1
2
250
260
270
280
290
300
310
320
330
340
350
360
400
410
420
430
440
460
470
480
490
500
510
520
530
540
550
600
610
630
640
650
660
670
680



Output port
B
810
Multiplexer
Channel 1
Channel 2
Channel 32
840
1
2
32
Demultiplexer
D
Auxiliary input port
818
820
825
E
Channel attenuation control
830
Multiplexer
C
Auxiliary output port
Channel 1
Channel 2
Channel 32
800
λ - Selective Demultiplexer
A
Input port

Fig.3.

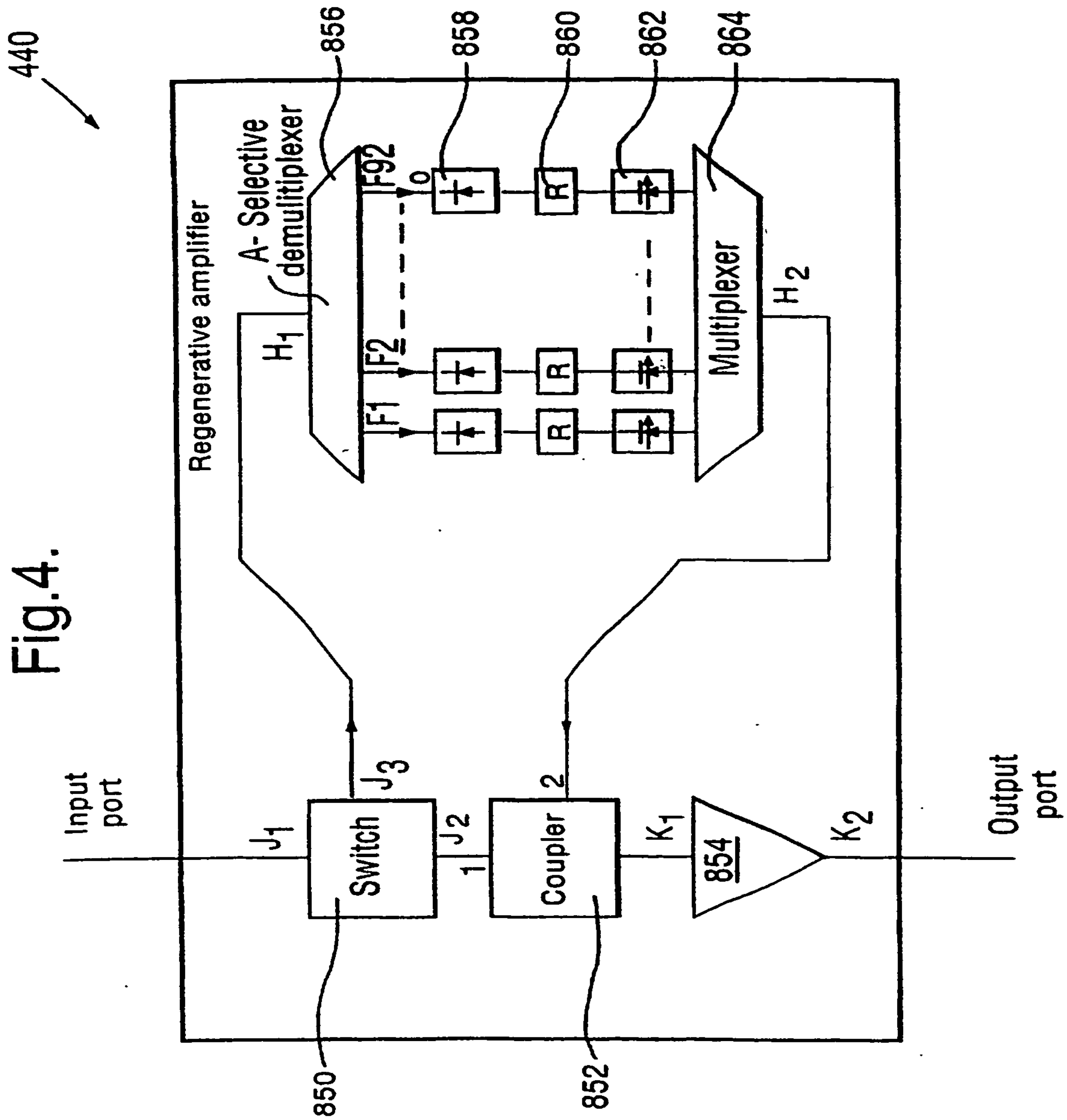
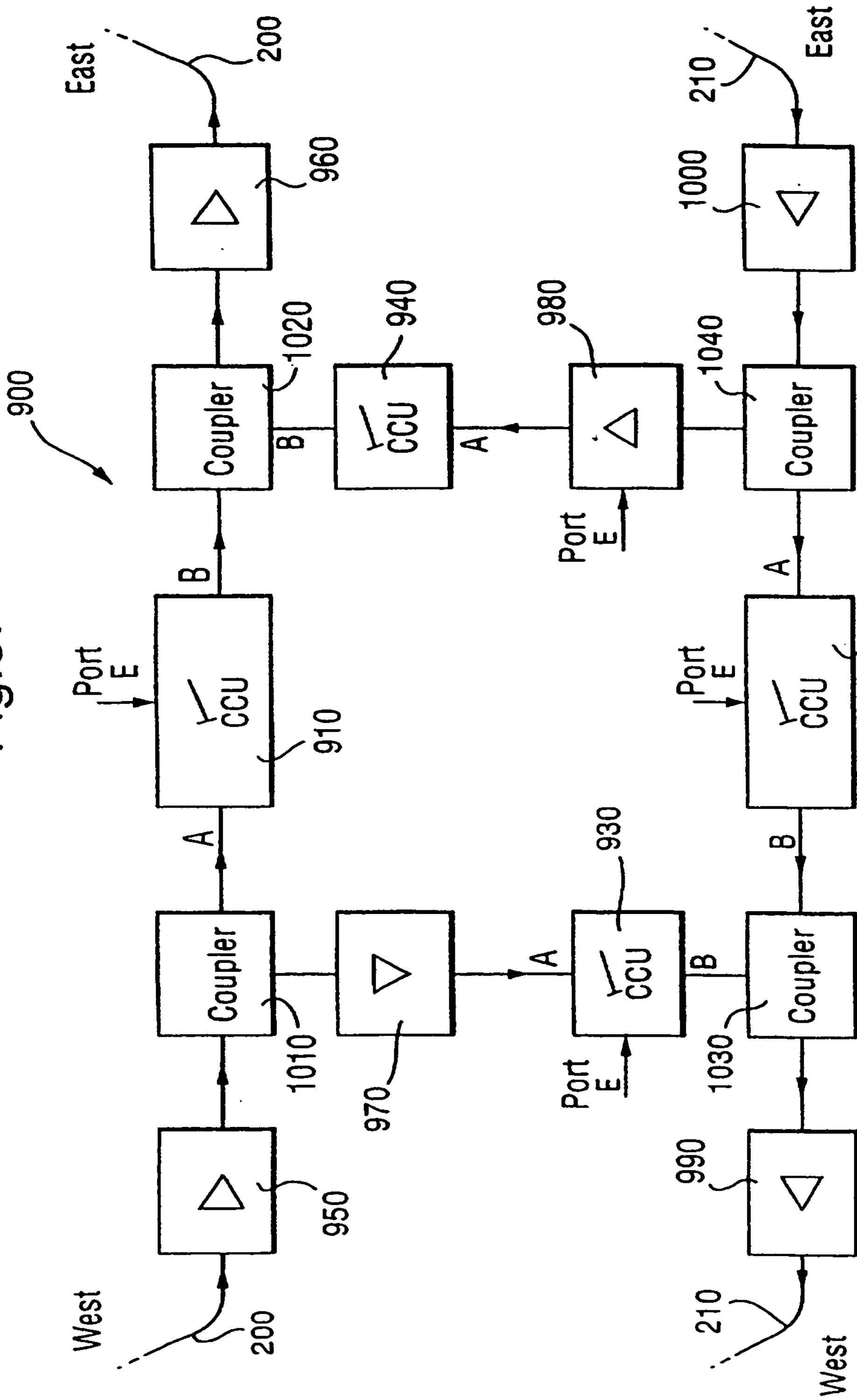

440
Regenerative amplifier
Input port
Output port
Switch
Coupler
850
852
854
856
858
860
862
864
J_1
J_2
J_3
1
2
K_1
K_2
H_1
H_2
A- Selective demulitiplexer
Multiplexer
F1
F2
F92
R

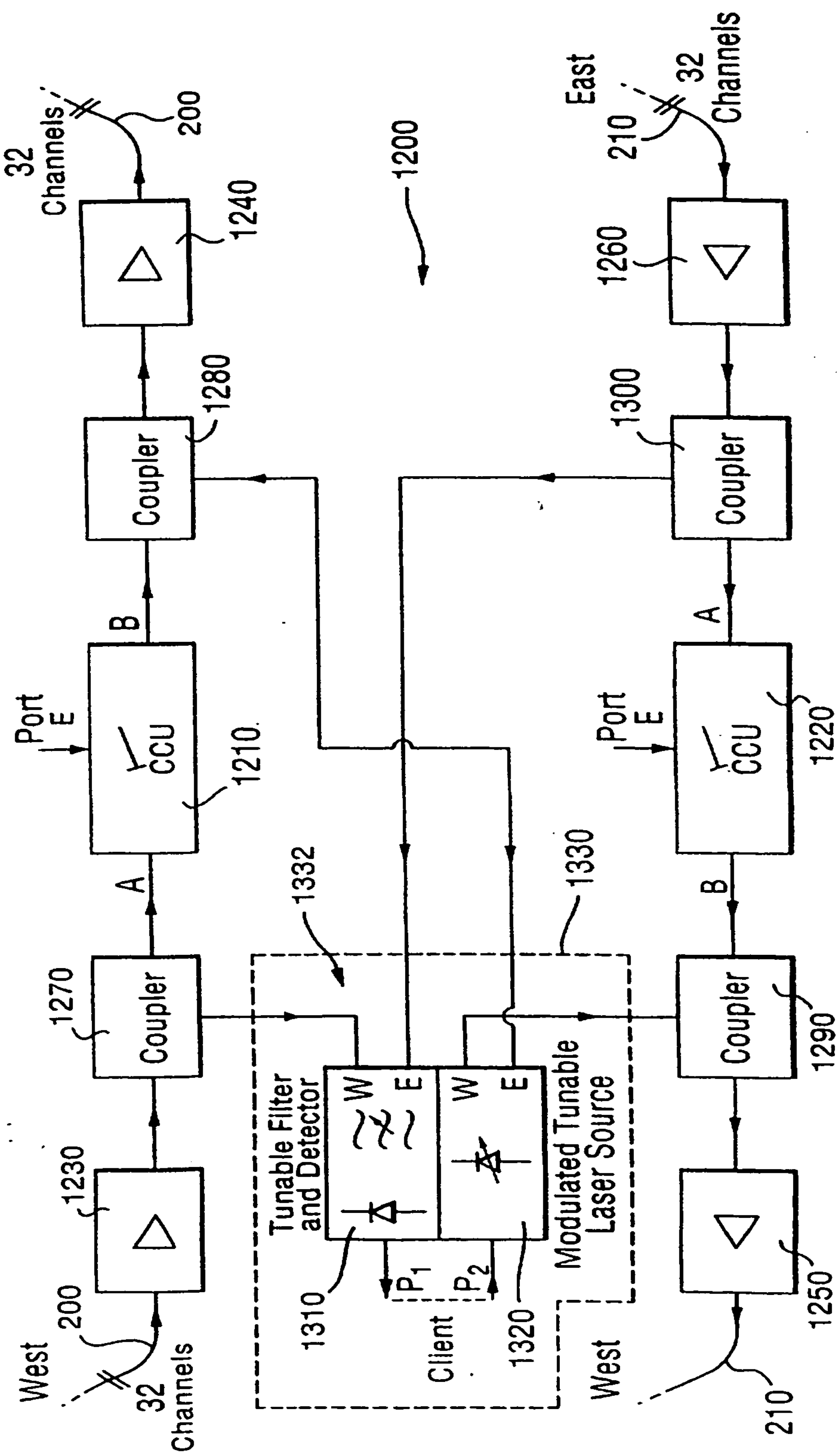
Fig.4.



East
200
East
210
960
1000
900
1020
940
980
1040
Coupler
B
CCU
A
Port E
Coupler
A
B
Port E
CCU
910
Port E
CCU
920
930
A
B
Coupler
1010
970
A
CCU
B
Coupler
1030
Port E
950
990
West
200
210
West

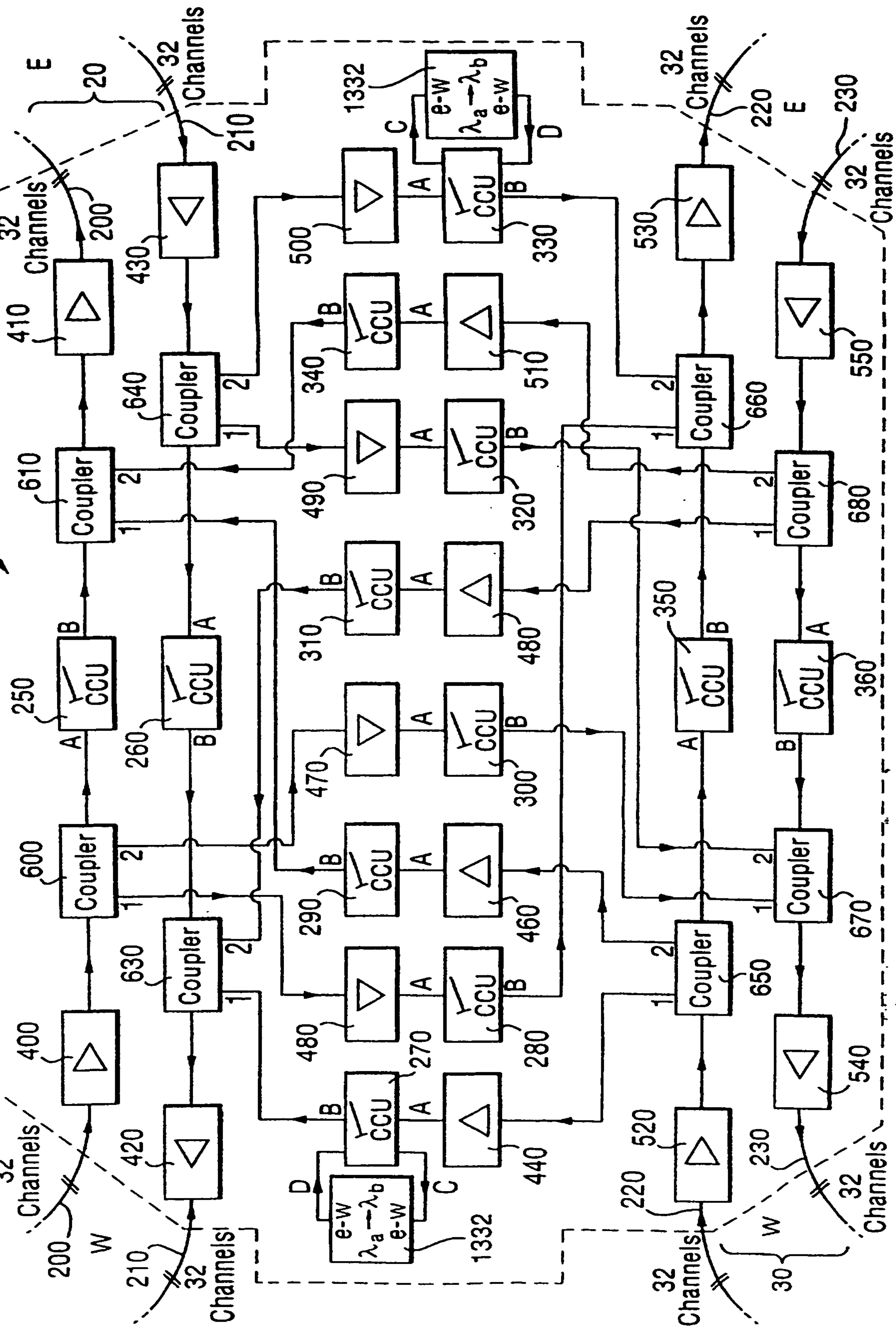
Fig.5.

Fig.6.



East
32 Channels
200
1240
1200
East
32 Channels
210
1260
1280
Coupler
1300
Coupler
B
A
Port E
CCU
1210
Port E
CCU
1220
A
B
1332
1330
1270
Coupler
1290
Coupler
1230
Tunable Filter and Detector
W
E
W
E
Modulated Tunable Laser Source
P_1
P_2
1310
1320
Client
West
200
32 Channels
West
1250
210

Fig.7.


1500
E
W
20
30
200
210
220
230
32 Channels
Coupler
CCU
A
B
C
D
1
2
e-W
$\lambda_a \rightarrow \lambda_b$
1332
250
260
270
280
290
300
310
320
330
340
350
360
400
410
420
430
440
460
470
480
490
500
510
520
530
540
550
600
610
630
640
650
660
670
680

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REGENERATIVE INTERFACE

The present invention is concerned with a regenerative interface for use in an optical communication system.

Conventional optical communication systems comprise nodes interconnected by optical fibre waveguides. Communication traffic is communicated between the nodes by sending optical radiation through the waveguides, the radiation being modulated by the communication traffic. Each node is operable to convert modulated radiation received thereat into corresponding electrical signals. Moreover, each node is further operable to convert electrical signals thereat into corresponding modulated optical radiation and emit the radiation into waveguides connected thereto. Electrical signals can be input and output from the nodes if required, for example to provide signals to clients connected to the nodes and to receive signals from the clients for transmission within the systems.

In the aforementioned conventional systems, the optical radiation propagating therein typically has a wavelength in the order of 1550 nm. This wavelength corresponds to a radiation frequency of around 200 THz and theoretically offers a maximum communication bandwidth in the order of 100 THz taking into consideration the Nyquist criterion, namely that carrier radiation must have a carrier frequency at least twice that of the highest frequency of a signal modulated onto the carrier radiation to circumvent aliasing and information loss. In practice, converting optical radiation into corresponding electrical signals at each node in the aforementioned conventional systems imposes a severe limitation on the communication bandwidth which can theoretically be provided by these systems. Such a limitation of bandwidth represents a serious problem.

The inventors have appreciated that it is highly desirable in an optical communication system to perform as much processing as possible within the optical domain to address the aforementioned bandwidth limitation problem and only convert between optical radiation and corresponding electrical signals when absolutely necessary for performing specialist functions, for example signal regeneration. Regeneration is required for at least partially reversing the effects of dispersion which arise when optical signals are transmitted through relatively long lengths of optical fibre waveguide, for example 100 km lengths of optical fibre. Attempts so far in the prior art to provide a nearly all-optical communication system have been frustrated by technical difficulties, particularly with regard to achieving all-optical reconfigurable radiation routing. The

inventors have therefore devised a regenerative interface for a communication system, the interface capable of providing flexible re-routing of communication traffic.

According to a first aspect of the present invention, there is provided a regenerative interface for an optical communication system comprising first and second optical paths for guiding information-bearing radiation partitioned into wavebands, the interface being operable to selectively communicate radiation corresponding to one or more of the wavebands from the first path to the second path, characterised in that

(a) the interface comprises waveband selective diverting means and regenerative coupling means;

(b) the diverting means is included in the first path and operable to divert radiation corresponding to the one or more of the wavebands from the first path to provide diverted radiation; and

(c) the coupling means is operable to regenerate radiation of one or more wavebands present in the diverted radiation and output the regenerated radiation to the second path.

The invention provides the advantage that the interface is capable of providing re-routable regenerative connections from the first path to the second path.

Advantageously, regeneration is performed for each of the wavebands separately. This involves the coupling means being operable to separate the diverted radiation into rays corresponding to one or more wavebands, to convert the radiation of each ray into a corresponding electrical signal, regenerate the electrical signal of each ray and use the regenerated electrical signal of each ray to modulate an associated source of radiation to generate regenerated radiation for output to the second path. Such regeneration avoids having to handle composite radiation directly comprising radiation components in a plurality of wavebands.

In some situations, regenerative amplification is not required and purely optical transmission through the interface is an advantage from bandwidth communication bandwidth considerations. Thus, preferably, the coupling means is selectably switchable between providing non-regenerative amplification and providing regenerative amplification.

It is convenient to construct the diverting means from proprietary components. Hence, preferably, the diverting means includes:

(a) waveband selective filtering means for separating at least part of the information-bearing radiation into spatially separated rays, each ray corresponding to radiation of an associated waveband; and

(b) liquid crystal attenuating means associated with each ray for selectively directing radiation corresponding to the waveband of the ray, the directed radiation contributing to the diverted radiation for the coupling means.

Likewise, for convenience of construction, the coupling means includes:

(a) waveband selective filtering means for separating at least part of the diverted radiation into spatially separated rays, each ray corresponding to radiation of an associated waveband; and

(b) liquid crystal attenuating means associated with each ray for selectively transmitting or diverting radiation corresponding to the waveband of the ray, thereby selectively providing radiation for selective regenerative amplification and subsequent output to the second path.

Where radiation from the coupling means is added to radiation propagating along the second path, it is desirable that there is no co-incidence of wavebands otherwise communication traffic data corruption will occur. Thus, beneficially, the second path includes waveband selective attenuating means for attenuating radiation of wavebands propagating along the second path, the coupling means operable to add radiation to radiation transmitted through the attenuating means, the attenuating means operable to attenuate radiation of wavebands propagating along the second path coincident in wavelength with radiation added by the coupling means.

When constructing the interface, it is desirable that proprietary components can be used for the fabricating the attenuating means. Thus, advantageously, the attenuating means includes:

(a) waveband selective filtering means for separating the radiation propagating along the second path into spatially separated rays, each ray corresponding to radiation of an associated waveband; and

(b) liquid crystal attenuating means associated with each ray for selectively transmitting or diverting radiation corresponding to the waveband of the ray, thereby selectively providing radiation for adding to that from the coupling means for further propagation along the second path.

When the interface is in operation, it is often convenient to switch communication traffic from one waveband to another to distribute communication traffic load more evenly in the system. In

order to achieve such redistribution, the coupling means preferably includes waveband switching means for transferring information conveyed on a first set of the wavebands of the diverted radiation to a second set of the wavebands in the diverted radiation output to the second path.

When implementing the switching means in practice, it is desirable to use proprietary components to make construction easier and less costly. Thus, advantageously, the waveband switching means comprises waveband selecting means for isolating radiation of a selected waveband in the diverted radiation, detecting means for converting the isolated radiation into a corresponding electrical signal, and an optical radiation source modulatable by the signal and operable to generate radiation bearing the signal and at a waveband mutually different to the selected waveband, the generated radiation for output to the second path.

However, there is an alternative all-optical implementation of the switching means which offers potentially greater bandwidth. Hence, beneficially, the waveband switching means comprises waveband selecting means for isolating radiation of a selected waveband in the diverted radiation, and an optical radiation source biased substantially at its lasing threshold, the source being operable to be stimulated by the isolated radiation such that stimulated radiation generated by the source is modulated by information carried by the isolated radiation, the stimulated radiation being at a waveband mutually different to the selected waveband, the stimulated radiation for output to the second path.

Conveniently, the interface is operable to cope with bi-directional communication along the first and second paths. Thus, preferably, the first and second paths are operable to support bi-directional radiation propagation therealong, and the interface is operable to couple radiation of one or more of the wavebands propagating in either direction along the first path to the second path for propagation in either direction therealong. The paths can include one or more of linear paths and ring paths.

In a practical implementation of the interface, the coupling means conveniently comprises at least one optical amplifier for amplifying the diverted radiation and an associated waveband selective channel control unit (CCU) for selectively transmitting radiation of one or more selected bands of the diverted radiation for output to the second path.

Moreover, it is advantageous that the interface is operable to be reconfigurable with regard to the wavebands selected. Furthermore, it is desirable that the interface can be incorporated into an optical communication system.

Embodiments of the invention will now be described, by way of example only, with reference to the following diagrams in which:

Figure 1 is a schematic illustration of an optical communication system according to the invention comprising a plurality of mutually coupled bi-directional communication rings;

Figure 2 is an illustration of a first type of optical interface of the system shown in Figure 1, the interface connecting between two bi-directional communication rings and providing E-W direction connections from one ring to another;

Figure 3 is a schematic diagram of a channel control unit included within the optical interface illustrated in Figure 2;

Figure 4 is an illustration of a regenerative amplifier included within the optical interface illustrated in Figure 2;

Figure 5 is an illustration of a second type of optical interface of the system shown in Figure 1, the connection providing connection between oppositely directed fibre loops of a bi-directional ring;

Figure 6 is an illustration of a wavelength switching transponder in an interface connecting two communication rings of the system shown in Figure 1; and

Figure 7 is an illustration of wavelength switching performed around channel control units of an interface of the system shown in Figure 1.

Referring now to Figure 1, an optical communication system according to the invention is indicated generally by 10. The system 10 comprises five interlinked bi-directional optical communication rings 20, 30, 40, 50, 60. The rings 20, 30, 40, 50, 60 are of diameters in a range of 10 km to 100 km and are operable to provide communication links at national and regional level. The rings 20, 30 include repeater nodes, for example a repeater node 65, represented by crosses around the rings 20, 30. Moreover, the ring 20 is connected through an interface 70 to the ring 30. Likewise, the ring 30 is connected through an interface 80 to the ring 40. The ring 40 is connected at first and second positions thereon through interfaces 90, 100 respectively to the ring 50. Likewise, the ring 50 is connected at third and fourth positions thereon through interfaces

110, 120 respectively to the ring 60. The interfaces 70 to 120 are similar and will be described in more detail later.

Each of the rings 20 to 60 comprises two parallel optical fibre waveguide loops, a first of which conveys optical radiation in a clockwise direction around the ring and a second of which conveys optical radiation therethrough in an anticlockwise direction around the ring. Two loops are included within each ring for ensuring that the ring can continue to function in an event of one of the loops becoming defective, for example suffering a fibre break. Moreover, the two loops enable traffic to be allocated between the loops to ensure that the system 10 is optimally loaded with communication traffic.

Communication traffic is modulated onto optical radiation which propagates through the system 10. Each fibre loop of the rings 20 to 60 is operable to carry modulated optical radiation, the radiation comprising 32 distinct modulated radiation components corresponding to respective 32 communication channels. Each channel is separated from its neighbouring channels by a wavelength difference of 0.8 nm; such a wavelength difference is equivalent to a channel frequency spacing of 100 GHz. Thus, each fibre conveys optical radiation nominally of 1550 nm wavelength comprising 32 channels spread over a wavelength range of substantially 25 nm.

Operation of the system 10 will now be described communicating communication traffic from a node A on the ring 20 to a node B on the ring 60; the system 10 is capable of communicating between other nodes therein, however nodes A, B are used here as an example. An electrical signal is received at the node A which converts it to corresponding optical radiation associated with one of the 32 channels. The radiation propagates from the node A through the repeater node 65 to the interface 70 and therefrom through the repeater nodes of the ring 30 to the interface 80. The radiation propagates from the interface 80 anticlockwise around the ring 40 to the interface 100. Next, the radiation propagates from the interface 100 around part of the ring 50 to the interface 120 through which it passes to the ring 60 and therearound to the node B. The node B receives the radiation and converts it into a corresponding electrical signal. Propagation of the radiation through the system 10 from node A to node B is performed purely optically except, as will be described later, where regeneration is performed.

In the process of propagating from the node A to the node B, the radiation passes through a number of repeaters and interfaces which, although providing optical amplification, result in the

radiation becoming degraded by attenuation, dispersion and added amplifier noise. Where possible, the system 10 includes regenerators and also phase dispersion and equalisation correction units at its nodes. Phase dispersion and equalisation corrections are performed purely optically.

Referring now to Figure 2, there is shown a first type of optical interface included within the system 10, namely the interface 70 shown included within a dotted line 180. The ring 20 comprises a first clockwise fibre loop 210 through which radiation propagates in a direction from east (E) to west (W) through the interface 70. Moreover, the ring 20 comprises a second anti-clockwise fibre loop 200 through which radiation propagates in a direction from west (W) to east (E) through the interface 70. East (E) and west (W) directions here are used to indicate propagation direction in the diagrams and are unrelated to actual East-West geographical directions.

Likewise, the ring 30 comprises a first clockwise fibre loop 220 through which radiation propagates in a direction west (W) to east (E) through the interface 70. Moreover, the ring further includes a second fibre loop 230 through which radiation propagates in a direction from east (E) to west (W) through the interface 70.

The interface 70 includes twelve channel control units (CCU) 250 to 360, optical amplifiers 400 to 430, 520 to 550, and regenerative optical amplifiers 440 to 500 interconnected as shown in Figure 2. The interface 70 further comprises fibre couplers 600 to 680 for coupling radiation from one fibre to another; the couplers are fabricated using optical fibre fusion splicing techniques although alternative types of couplers are useable in substitution. On account of its complexity, the interface 70 is a relatively expensive item but provides great flexibility when selectively coupling optical radiation between the rings 20, 30. Where such flexibility is not required, the interface 70 can be simplified to reduce cost; such simplification will be described later.

Detailed interconnection of the couplers 600 to 680, the CCUs 250 to 360 and the optical amplifiers 400 to 550 will now be described with reference to Figure 2. The couplers 600 to 680 are mutually similar. Moreover, the amplifiers 400 to 550 are also mutually similar. Furthermore, the CCUs 250 to 360 are mutually similar.

The fibre 200 of the ring 20 from the westerly (W) direction is connected to an input port of the amplifier 400. The amplifier 400 includes an output port which is connected through an optical fibre to the coupler 600 and therethrough to an input port A of the CCU 250. The CCU 250 comprises an output port B which is connected through an optical fibre to the coupler 610 and therethrough to an input port of the amplifier 410. The fibre 200 in an easterly (E) direction is connected to an output port of the amplifier 410.

Likewise, the fibre 210 of the ring 20 from the easterly (E) direction is connected to an input port of the amplifier 430. The amplifier 430 includes an output port which is connected through an optical fibre to the coupler 640 and therethrough to an input port A of the CCU 260. The CCU 260 comprises an output port B which is connected through an optical fibre to the coupler 630 and therethrough to an input port of the amplifier 420. The fibre 210 in a westerly (W) direction is connected to an output port of the amplifier 420.

Similarly, the fibre 220 of the ring 30 from the westerly (W) direction is connected to an input port of the amplifier 520. The amplifier 520 includes an output port which is connected through an optical fibre to the coupler 650 and therethrough to an input port A of the CCU 350. The CCU 350 comprises an output port B which is connected through an optical fibre to the coupler 660 and therethrough to an input port of the amplifier 530. The fibre 220 in an easterly (E) direction is connected to an output port of the amplifier 530.

Likewise, the fibre 230 of the ring 30 from the easterly (E) direction is connected to an input port of the amplifier 550. The amplifier 550 includes an output port which is connected through an optical fibre to the coupler 680 and therethrough to an input port A of the CCU 360. The CCU 360 comprises an output port B which is connected through an optical fibre to the coupler 670 and therethrough to an input port of the amplifier 540. The fibre 230 in a westerly (W) direction is connected to an output port of the amplifier 540.

The couplers 600 to 640 are connected to the couplers 650 to 680 through a series of connection chains, each chain comprising an optical amplifier and an associated CCU connected in series.

Connections from the ring 20 to the ring 30 will now be described. The coupler 600 includes first and second output ports. The first port of the coupler 600 is connected via an optical fibre through the amplifier 450 and then through the CCU 280 to a first input port of the coupler 660.

Additionally, the second port of the coupler 600 is connected via an optical fibre through the amplifier 470 and through the CCU 300 to a first input port of the coupler 670. Moreover, the coupler 640 includes first and second output ports. The first port of the coupler 640 is connected via an optical fibre through the amplifier 490 and through the CCU 320 to a second input port of the coupler 670. Furthermore, the second port of the coupler 640 is connected via an optical fibre through the amplifier 500 and through the CCU 330 to a second input port of the coupler 660.

Next, connections from the ring 30 to the ring 20 will be described. The coupler 650 includes first and second output ports. The first port of the coupler 650 is connected via an optical fibre through the amplifier 440 and through the CCU 270 to a first input port of the coupler 630. Likewise, the second port of the coupler 650 is connected via an optical fibre through the amplifier 460 and then through the CCU 290 to a first input port of the coupler 610. Moreover, the coupler 680 includes first and second output ports. The first port of the coupler 680 is connected via an optical fibre through the amplifier 480 and then through the CCU 310 to a second input port of the coupler 630. Furthermore, the second port of the coupler 680 is connected via an optical fibre through the amplifier 510 and then through the CCU 340 to a second input port of the coupler 610.

Each CCU is capable of selectively attenuating radiation propagating therethrough corresponding to one or more of the 32 channels. Moreover, applying selective attenuation at the CCUs 250, 260, 350, 360 has the effect of diverting optical radiation to the couplers 600, 640, 650, 680 respectively preceding the CCUs. Such diversion also enables radiation to be added for the diverted channels at the couplers 610, 630, 660, 670 following the CCUs 250, 260, 350, 360 respectively.

In operation, the interface 70 is capable of coupling specific selected channels from the ring 20 and directing them in either direction around the ring 30. Furthermore, in a reciprocal manner, the interface 70 is capable of coupling specific selected channels from the ring 30 and directing them in either direction around the ring 20. Moreover, the interface 70 provides a signal regeneration characteristic for radiation propagating from the north (N) to south (S) direction, north and south here being unrelated to geographical north and south directions but merely used for referring to directions on the diagrams.

In the communication system 10, it is not always necessary that its nodes provide the full connection functionality of the interface 70. When such extensive functionality is not required, the interface 70 can be simplified to reduce its complexity and cost by omitting some of the chains.

In the interface 70, equalisation functions can be included within the aforementioned chains. It is preferable that such functions are performed optically. Optical equalization is achievable using polarization dependent beam splitters and switched optical delay lines in a manner as described in a US patent no. US 5 859 939 which is incorporated herein by reference.

Electrical regeneration is performed in the regenerative amplifiers 440 to 500. Regeneration can, if required, be implemented in the repeater nodes around the rings 20, 30 in addition to, or in substitution for, regeneration within the interface 70.

In practice, commercially available optical amplifiers, CCUs and optical couplers can be connected together to construct the interface 70. For example, the optical amplifiers 400 to 550 are preferably proprietary units which incorporate optically-pumped erbium-doped super-fluorescent optical fibres as active optical gain components. Likewise, the CCUs 250 to 360 are commercially available from vendors based in the United States of America; the vendors supply CCUs in units, each unit comprising a pair of CCUs. Each incorporates optical gratings, a matrix of liquid crystal apertures functioning as variable optical attenuators and free-space optical paths to achieve a compact construction and a low minimum insertion loss in the order of 6 dB from the CCU optical input port to the CCU optical output port when its attenuators are set to provide nominally zero attenuation. It is beneficial to the performance of the interface 70 to use such commercially available CCUs exhibiting low insertion losses in view of the number of CCUs employed within the interface 70; such low insertion loss CCUs reduce amplification requirements thereby improving system 10 signal-to-noise performance.

In order to further elucidate operation of the interface 70, the CCUs 250 to 360 will be described in further detail with reference to Figure 3. In Figure 3, there is shown an schematic representation of the CCU 250; the other CCUs 260 to 360 are similar in construction and performance to the CCU 250.

The CCU 250 includes an optical input port A for receiving radiation, an optical output port B for outputting radiation, an auxiliary optical output C, an auxiliary optical input D, and an electrical input port E for receiving electrical control signals for controlling operation of the CCU 250; the port E is, for example, used for receiving electrical signals for controlling attenuation settings of the attenuators. The CCU 250 comprises within it a demultiplexer 800, a multiplexer 810 and a matrix 818 of 32 liquid crystal attenuators shown included within a dotted line 820; an attenuator 815 is an example of one attenuator within the matrix 818. The demultiplexer 800 includes 32 optical outputs which are directed to convey radiation to their corresponding liquid crystal attenuators in the matrix 818. Outputs from the attenuators are directed to optical inputs of the multiplexer 810 which recombines radiation transmitted through the attenuators to provide output radiation at the port B. When the attenuators are set to attenuate radiation incident thereupon, the radiation is diverted towards a multiplexer 830 which is operable to combine the diverted radiation and provide a corresponding radiation output at the port C. Likewise, the port D is connected to a demultiplexer 840 which is operable to guide radiation input at the port D to the attenuators for propagating onwards to the multiplexer 810 for subsequent output at the port B. In the interface 70, the ports C and D of the CCUs are not normally used although they can be employed in special circumstances, for example when performing a wavelength shift to switch traffic from one channel to another; such a shift will be described later.

The attenuators are electronically controllable to provide an attenuation through each attenuator in a range of 0.1 dB to 30 dB. The CCUs supplied by the aforementioned vendors and incorporated within the interface 70 use free-space optics to obtain a minimum insertion loss of 6 dB. If the CCU where not constructed using such free-space optics, for example using more conventional fusion-spliced fibre optics, optical losses through the demultiplexer 800 and the multiplexer 810 would be around 7.5 dB and 4.5 dB respectively resulting in a total minimum insertion loss of 12 dB. Moreover, CCUs for use in the interface 70 would be considerably more expensive and bulky were they not to employ such a compact free-space optical architecture.

The demultiplexer 800 is operable to filter composite radiation input at the port A into separate radiation components corresponding to each of the aforementioned 32 channels at 0.8 nm wavelength channel spacing. Thus, each attenuator can attenuate the radiation component corresponding thereto, thereby enabling each channel represented in radiation intput to the demultiplexer 800 to be selectively attenuated and diverted to the port C. In the interface 70, attenuation of a radiation component corresponding to a particular channel in the CCU 250 results

in its radiation being diverted through the coupler 600 to its associated first and second output ports. A similar characteristic pertains to the CCUs 260, 350, 360 connected in-line in the rings 20, 30.

The CCUs 250 to 360 are controlled by electrical instructions sent thereto from a management control unit (not shown) tasked with routing communication traffic within the system 10 in response to client demand. The interface 70 is therefore designed to be highly reconfigurable thereby enabling communication traffic of any channels propagating in one of the rings to be selectively coupled to another of the rings in potentially both ring directions, namely in both directions of radiation propagation within the rings.

The regenerative amplifiers 440 to 500 will now be described with reference to Figure 4. The amplifiers 440 to 500 are similar, hence only amplifier 440 will be described in further detail. The regenerative amplifier 440 comprises an optical switch 850, a coupler 852, an optical amplifier 854, a waveband selective demultiplexer 856 including 32 outputs connected through mutually similar regenerating chains to a multiplexer 864. As an example, one of the chains comprises a detector 858, an electrical regeneration unit 860 and a modulated laser source 862. Each chain is connected at its output to a corresponding optical input of the multiplexer 864. The optical amplifier 854 is operable to provide non-regenerative optical amplification only.

Interconnection of component parts of the regenerative amplifier 440 will now be described. An input port of the amplifier 440 is connected to an optical input port J_1 of the optical switch 850. An output J_2 of the optical switch is connected through a first optical input port of the coupler 852 and therefrom through the coupler 852 to an input port K_1 of the optical amplifier 854. An output port K_2 of the amplifier 854 is connected to provide an optical output for the regenerative amplifier 440.

An output port J_3 of the switch 850 is connected to an optical input port H_1 of the demultiplexer 856. The demultiplexer 856 includes 32 optical output ports F_1 to F_{32} at which radiation input to the optical port H_1 is output, each of the 32 outputs bearing radiation corresponding to a associated waveband of the system 10. Each of the 32 outputs is connected through its associated regeneration chain to a corresponding input of the multiplexer 864. An optical output port H_2 of the multiplexer 864 is connected to a second input port of the coupler 852 and therefrom through the coupler 852 to the input port K_1 of the amplifier 854.

Operation of the regenerative amplifier 440 will now be described with reference to Figure 4. The input port J_1 receives radiation. Depending on how the switch 850 is programmed, it either:

(a) diverts the radiation through the coupler 852 for amplification in the amplifier 854 for subsequent output at the port K_2; or

(b) diverts the radiation to the demultiplexer 856 which separates the radiation into associated radiation components corresponding to the wavebands;, each component propagates through its associated chain in which regeneration occurs, and therefrom when regenerated to the multiplexer 864 which combines the regenerated radiation components received from the chains to provide regenerated radiation which is output at the port H_2 to the coupler 852; the coupler 852 couples the regenerated radiation to the optical amplifier 854 for optical amplification therein and subsequent output at the output port K_2.

Thus, the regenerative amplifier 440 is capable of selectively providing simple optical amplification or, alternatively, regenerative amplification.

Operation of the chains of the amplifier 440 will now be described in further detail. The detector 858 comprises a photodiode operable to convert optical radiation (o) received thereat into a corresponding electrical signal (e) at its electrical output Z_1. The regeneration unit 860 is operable to receive an electrical signal (e) comprising a serial stream of data, for example at a bit-rate of 10 Gbits/s, and submit it to hysteresis and synchronisation processes to make its data edges more closely resemble their original form. The source 862 is operable to receive an electrical signal (e) from its associated regeneration unit 860 and use it to modulate a laser tuned to output radiation at the waveband associated with the chain. Each of the chains of the amplifier 440 function in a similar manner except that each chain is arranged to output modulated radiation in a waveband corresponding thereto.

Although the interface 70 is capable of providing interconnection between bi-directional rings, for example between the rings 20, 30, there often arises a requirement to switch a particular channel within a bi-directional ring from one direction to another, for example from a clockwise loop of the ring to an associated anti-clockwise loop thereof. In order to achieve such a selective switching function, a simplified version of the interface 70 can be included in the ring. Such a simplified version of the interface 70 is illustrated in Figure 5 and indicated generally by 900. The simplified interface 900 comprises four CCUs 910 to 940, six optical amplifiers 950 to 1000 and four fibre couplers 1010 to 1040. The CCUs 910 to 940 are each similar to the CCU 250.

Interconnection of the CCUs, amplifiers and fibre couplers of the simplified interface 900 will now be described. The amplifiers 950, 960, the CCU 910 and the couplers 1010, 1020 are connected inline in the second fibre loop of the ring 20. A fibre 200 of the second loop in a westerly (W) direction is connected to an optical input of the amplifier 950. An optical output of the amplifier 950 is connected through an optical fibre to the coupler 1010 and therethrough to an optical input port A of the CCU 910. An optical output port B of the CCU 910 is connected through an optical fibre to the coupler 1020 and therethrough to an optical input of the amplifier 960. An optical output of the amplifier 960 is connected to the fibre 200 directed in an easterly (E) direction.

In a similar manner, the amplifiers 990, 1000, the CCU 920 and the couplers 1030, 1040 are connected inline in the first fibre loop of the ring 20. A fibre 210 of the first loop in an easterly (E) direction is connected to an optical input of the amplifier 1000. An output of the amplifier 1000 is connected through an optical fibre to the coupler 1040 and therethrough to an optical input port A of the CCU 920. An optical output port B of the CCU 920 is connected through an optical fibre to the coupler 1030 and therethrough to an optical input of the amplifier 990. An optical output of the amplifier 990 is connected to the fibre 210 directed in a westerly (W) direction.

The amplifier 970 and its associated CCU 1030 are connected in series and are operable to provide a first chain selectively linking communication traffic from the second loop comprising the fibre 200 to the first loop comprising the fibre 210. Likewise, the amplifier 980 and its associated CCU 940 are operable to provide a second chain selectively linking communication traffic from the first loop to the second loop.

In operation, the simplified interface 900 can block, by virtue of the CCUs 910, 920, communication traffic associated with specific channels flowing within the loops and direct the traffic to a chain which can selectively transmit one or more of the channels depending upon instructions sent to the port E of its CCU. In general, the CCU 910 will be set to attenuate radiation of one or more channels which the CCU 930 is set to selectively transmit. Likewise, the CCU 920 will be set to attenuate radiation of one or more channels which the CCU 940 is set to selectively transmit. Thus, the interface 900 enables specific selected channels to be switched from propagating in one direction around the ring 20 to an opposite direction relative thereto.

The interface enables the volume of communication traffic to be more equally distributed between the two loops of the ring 20, thereby enabling the system 10 to be more fully utilised. The interface 900 also provides optical amplification which assists to maintain optical radiation amplitude within the system 10.

When coupling communication traffic between rings in the system 10, and also when switching direction of selected channels within one or more rings of the system 10, it is frequently convenient to shift communication traffic from one channel to another along a particular loop or ring; this is often referred to as wavelength shifting. Wavelength shifting enables the channels of the system 10 to be fully utilised to carry communication traffic thereby assisting to optimise the traffic throughput capacity of the system 10.

Such wavelength shifting is preferably performed purely in the optical domain to avoid imposing bandwidth restrictions on the system 10; optical wavelength shifting can be achieved using optical heterodyne techniques in non-linear optical components capable of performing optical mixing. Alternatively, wavelength shifting can also be achieved by using optical radiation at a first frequency to pump a laser biased near its lasing threshold and tuned to output optical radiation at a second frequency, thereby enabling communication traffic modulated onto the radiation of the first frequency to be modulated onto radiation output from the laser at the second frequency; if the radiation of the first frequency corresponds to one channel of the system 10 and radiation of the second frequency to another channel, switching of traffic from one channel to another can be achieved.

Wavelength switching can also be performed by converting modulated radiation at a first wavelength associated with a specific channel of the system 10 to a corresponding electrical signal and then using the electrical signal to amplitude modulate a laser to output radiation amplitude modulated by the electrical signal at a second wavelength associated with another specific channel of the system 10. Such wavelength switching is often found to be required when coupling communication traffic from one ring of the system 10 to another thereof.

Referring now to Figure 6, there is shown a wavelength switching transponder in an interface connecting two communication rings of the system 10. The interface is indicated generally by 1200 and comprises two CCUs 1210, 1220, four optical amplifiers 1230 to 1260, four optical couplers 1270 to 1300, a tunable filter and detector 1310, and a modulated tunable laser source

1320. Each of the two CCUs 1210, 1220 are similar to the CU 250 described earlier. The amplifiers 1230, 1240, the CCU 1210 and the couplers 1270, 1280 are connected into the second loop of the ring 20, the loop including the fibre 200. Likewise, the amplifiers 1250, 1260, the CCU 1220 and the couplers 1290, 1300 are connected into the first loop of the ring 30, the loop including the fibre 210. The tunable filter and detector 1310 and the source 1320 constitute a transponder shown within a dotted line 1330 which is connected to the couplers and operable to wavelength shift a selected channel from one of the loops and output at another wavelength back onto the same loop or an alternative loop.

Interconnection within the interface 1200 will now be described. The fibre 210 of the first loop of the ring 20 from a westerly (W) direction is connected to an optical input of the amplifier 1230. An optical output from amplifier 1230 is connected to the coupler 1270 and therethrough to an optical input port A of the CCU 1210. An optical output port B of the CCU 1210 is connected via an optical fibre to the coupler 1280 and therethrough to an optical input of the amplifier 1240. The fibre 200 in an easterly (E) direction of the second loop is connected to an optical output of the amplifier 1240.

Likewise, the fibre 210 of the first loop of the ring 30 from an easterly (E) direction is connected to an optical input of the amplifier 1260. An optical output from amplifier 1260 is connected to the coupler 1300 and therethrough to an optical input port A of the CCU 1220. An optical output port B of the CCU 1220 is connected via an optical fibre to the coupler 1290 and therethrough to an optical input of the amplifier 1250. The fibre 210 in a westerly (W) direction of the first loop of the ring 30 is connected to an optical output of the amplifier 1250.

An optical output of the coupler 1270 is connected through an optical fibre to a first optical input of the tunable filter and detector 1310. Similarly, an optical port of the coupler 1300 is connected through an optical fibre to a second optical input of the filter and detector 1310.

An optical input of the coupler 1290 is connected through an optical fibre to a first optical output of the laser source 1320. Similarly, an optical input port of the coupler 1280 is connected through an optical fibre to a second optical output of the laser source 1320.

The tunable filter and detector 1310 includes a coupler to combine radiation received at its first and second ports, and also a tunable filter and a detector. It is operable to receive radiation, filter

out radiation corresponding to a channel to be shifted and to detect the filtered radiation to generate a corresponding demodulated electrical signal which is provided to the output P1. The source includes a tunable laser for generating output radiation modulated by an electrical signal applied at the electrical input P2 of the source 1320. When the laser source 1320 is tuned to operate at a frequency which is mutually different from the filter frequency of the of the filter and detector 1310, frequency shifting of traffic between channels is achieved when the electrical signal output at P1 is injected at the input P2.

The CCU 1210 is operable to attenuate one or more selected channels included in radiation propagating around the second loop of the ring 20. Such attenuation diverts the attenuated radiation to the coupler 1270 and onwards to the first input of the filter and detector 1310. When the filter and detector 1310 is tuned to the wavelength of a channel attenuated at the CCU 1210, radiation propagates through to the detector and gives rise to an electrical signal at the output P1. The signal from the output P1 is directed to the input P2 and is operable to modulate radiation generated by the source 1320 which selectively outputs the modulated radiation at the first or second output depending upon instructions received from the management control unit (not shown). When the radiation is output at the second output of the laser source 1320, it propagates to the coupler 1280 and is coupled into the second loop to propagate further in an easterly (E) direction through the fibre 200 around the second loop of the ring 20. Conversely, when the radiation is output at the first output of the laser source 1320, it propagates to the coupler 1290 and passes therethrough to the amplifier 1250 and onwards in a westerly (W) direction along the fibre 210 of the first loop of the ring 30.

The CCU 1220 is also operable to selectively attenuate radiation corresponding to one or more selected channels propagating in the first loop of the ring 30 and direct the radiation through the coupler 1300 to the second input of the filter and detector 1310. The filter and detector 1310 are operable to isolate radiation components and detect them to generate a corresponding electrical signal at the output P1. The electrical signal, when directed to the source 1320, modulates the source 1320 to provide modulated radiation which is selectively directable to the ring 20 or to the ring 30.

The interface 1200 is thus capable of selectively shifting communication traffic from one channel to another. Moreover, it is further capable of receiving such traffic from either the ring 20 or the ring 30 and selectively outputting the traffic, when channel shifted, onto either the ring 20 or the

ring 30. The interface is thus capable of performing flexible and reconfigurable frequency shifting and routing functions.

The transponder shown in Figure 6 included within the dotted line 1330 and indicated by 1332 can be included within the interface 70 illustrated in Figure 1 to provide a modified interface indicated generally by 1500 in Figure 7. Such a modified interface 1500 not only provides a high degree of reconfigurable channel connection control but also enable communication traffic to be switched between channels to ensure that the system 10 is operating optimally to circumvent grossly unequal distribution of traffic between available channels.

Within the interface 1500, each transponder 1332 is connected with its filter and detector 1310 inputs coupled to its associated CCU optical output port C, and its source 1320 outputs coupled to its associated CCU optical input port D. Although transponders 1332 are illustrated coupled to the CCUs 270, 330 only, more transponders can be incorporated into the interface 1500 if necessary such that up to all the CCUs 270 to 340 have associated transponders 1332 capable of performing wavelength shifting of communication traffic directed therethrough.

It will be appreciated that modifications can be made to the system 10, and to the interfaces 70, 900, 1200, 1500 without departing from the scope of the invention. For example, although the system 10 is illustrated with a sending node A and a receiving node B, the system 10 can have a large number of sending and receiving nodes distributed generally therearound. The system 10 can be modified to include a combination of ring and linear communication paths interlinked by interfaces of a type included amongst the interfaces 70, 900, 1200, 1500 at various locations. Moreover, the interfaces 70, 900, 1200, 1500 can be simplified or made more complex as described above to suit particular system reconfiguration requirements. For example, the system 10 can be modified to include 100 bi-directional rings, each ring comprising 10 interfaces similar to the interface 900, the rings interconnected together through interfaces similar to the interface 1500. Furthermore, the system 10 can be modified to include optical fibre in its rings 20 to 60 capable of supporting soliton propagation so that greater communication distances can be served by the system without requiring additional regeneration and repeaters. Additionally, where technical design allows, the regenerative amplifiers are preferable implemented as devices which perform regeneration within the optical domain without needing to convert radiation to corresponding electrical signals.

CLAIMS

1. A regenerative interface for an optical communication system comprising first and second optical paths for guiding information-bearing radiation partitioned into wavebands, the interface being operable to selectively communicate radiation corresponding to one or more of the wavebands from the first path to the second path, characterised in that
   (a) the interface comprises waveband selective diverting means and regenerative coupling means;
   (b) the diverting means is included in the first path and operable to divert radiation corresponding to the one or more of the wavebands from the first path to provide diverted radiation; and
   (c) the coupling means is operable to regenerate radiation of one or more wavebands present in the diverted radiation and output the regenerated radiation to the second path.

2. An interface according to Claim 1 wherein the coupling means is operable to separate the diverted radiation into rays corresponding to one or more wavebands, to convert the radiation of each ray into a corresponding electrical signal, regenerate the electrical signal of each ray and use the regenerated electrical signal of each ray to modulate an associated source of radiation to generate regenerated radiation for output to the second path.

3. An interface according to Claim 1 or 2 wherein the coupling means is selectably switchable between providing non-regenerative amplification and providing regenerative amplification.

4. An interface according to Claim 1, 2 or 3 wherein the diverting means includes:
   (a) waveband selective filtering means for separating at least part of the information-bearing radiation into spatially separated rays, each ray corresponding to radiation of an associated waveband; and
   (b) liquid crystal attenuating means associated with each ray for selectively directing radiation corresponding to the waveband of the ray, the directed radiation contributing to the diverted radiation for the coupling means.

5. A system according to Claim 1 or 2 wherein the coupling means includes:
   (a) waveband selective filtering means for separating at least part of the diverted radiation into spatially separated rays, each ray corresponding to radiation of an associated waveband; and
   (b) liquid crystal attenuating means associated with each ray for selectively transmitting or diverting radiation corresponding to the waveband of the ray, thereby selectively providing radiation for selective regenerative amplification and subsequent output to the second path.

6. An interface according to any preceding claim wherein the second path includes waveband selective attenuating means for attenuating radiation of wavebands propagating along the second path, the coupling means operable to add radiation to radiation transmitted through the attenuating means, the attenuating means operable to attenuate radiation of wavebands propagating along the second path coincident in wavelength with radiation added by the coupling means.

7. An interface according to Claim 6 wherein the attenuating means includes:
   (a) waveband selective filtering means for separating the radiation propagating along the second path into spatially separated rays, each ray corresponding to radiation of an associated waveband; and
   (b) liquid crystal attenuating means associated with each ray for selectively transmitting or diverting radiation corresponding to the waveband of the ray, thereby selectively providing radiation for adding to that from the coupling means for further propagation along the second path.

8. An interface according to any one of Claims 1 to 7 wherein the coupling means includes waveband switching means for transferring information conveyed on a first set of the wavebands of the diverted radiation to a second set of the wavebands in the diverted radiation output to the second path.

9. An interface according to Claim 8 wherein the waveband switching means comprises waveband selecting means for isolating radiation of a selected waveband in the diverted radiation, detecting means for converting the isolated radiation into a corresponding

electrical signal, and an optical radiation source modulatable by the signal and operable to generate radiation bearing the signal and at a waveband mutually different to the selected waveband, the generated radiation for output to the second path.

10. An interface according to Claim 8 wherein the waveband switching means comprises waveband selecting means for isolating radiation of a selected waveband in the diverted radiation, and an optical radiation source biased substantially at its lasing threshold, the source being operable to be stimulated by the isolated radiation such that stimulated radiation generated by the source is modulated by information carried by the isolated radiation, the stimulated radiation being at a waveband mutually different to the selected waveband, the stimulated radiation for output to the second path.

11. An interface according to any preceding claim wherein the first and second paths are operable to support bi-directional radiation propagation therealong, and the interface is operable to couple radiation of one or more of the wavebands propagating in either direction along the first path to the second path for propagation in either direction therealong.

12. An interface according to according to any preceding claim wherein the paths include one or more of linear paths and ring paths.

13. An interface according to any preceding claim wherein the coupling means comprises at least one optical amplifier for amplifying the diverted radiation and an associated waveband selective channel control unit (CCU) for selectively transmitting radiation of one or more selected bands of the diverted radiation for output to the second path.

14. An interface according to any preceding claim operable to be reconfigurable with regard to the wavebands selected.

15. An optical communication system incorporating an interface according to any preceding claim.

16. An interface substantially as hereinbefore described with reference to one or more of Figures 1 to 7.

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Claims searched: 1-16

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): H4B (BK20, BK20T, BK20T1, BKX, BN).

Int Cl (Ed.7): H04B: 10/20, 10/213, H04J: 14/02, H04Q: 11/00

Other: Online : WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2 321 809 A	(STC) See especially the abstract, figure 1, and page 10, lines 4-7.	1, 2, 12, 13, & 15.
X	WO 97/18685 A1	(Ericsson) See especially the abstract, figure 4, and page 10, line 6, to page 11, line 30.	1, 2, 8-10, & 12-15.
X	US 5 726 785	(France Telecom) See especially the abstract, figures 1 & 3, and column 3, line 35, to column 5, line 10.	1, 2, 12, 13, & 15.

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